

EXPLORING THE DARK UNIVERSE WITH THE SOUTH POLE TELESCOPE

SASHA RAHLIN



SPT3G COLLABORATION

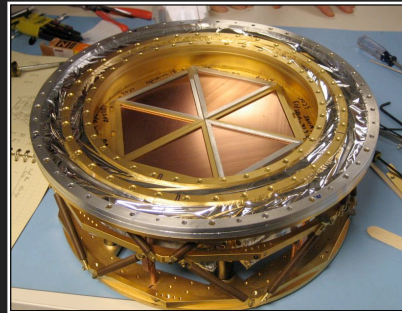


THE SOUTH POLE TELESCOPE

- ▶ 10-m submm-quality wavelength telescope
 - ▶ 90, 150, 220 GHz
 - ▶ 1.6, 1.2, 1.0 arcmin resolution

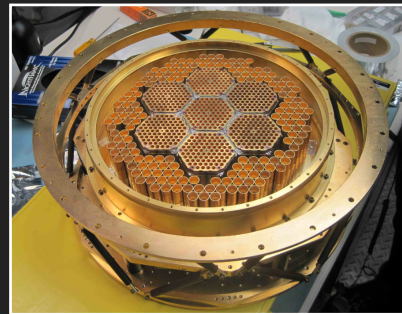
- ▶ **2007: SPT-SZ**

- ▶ 960 detectors
- ▶ 90, 150, 220 GHz



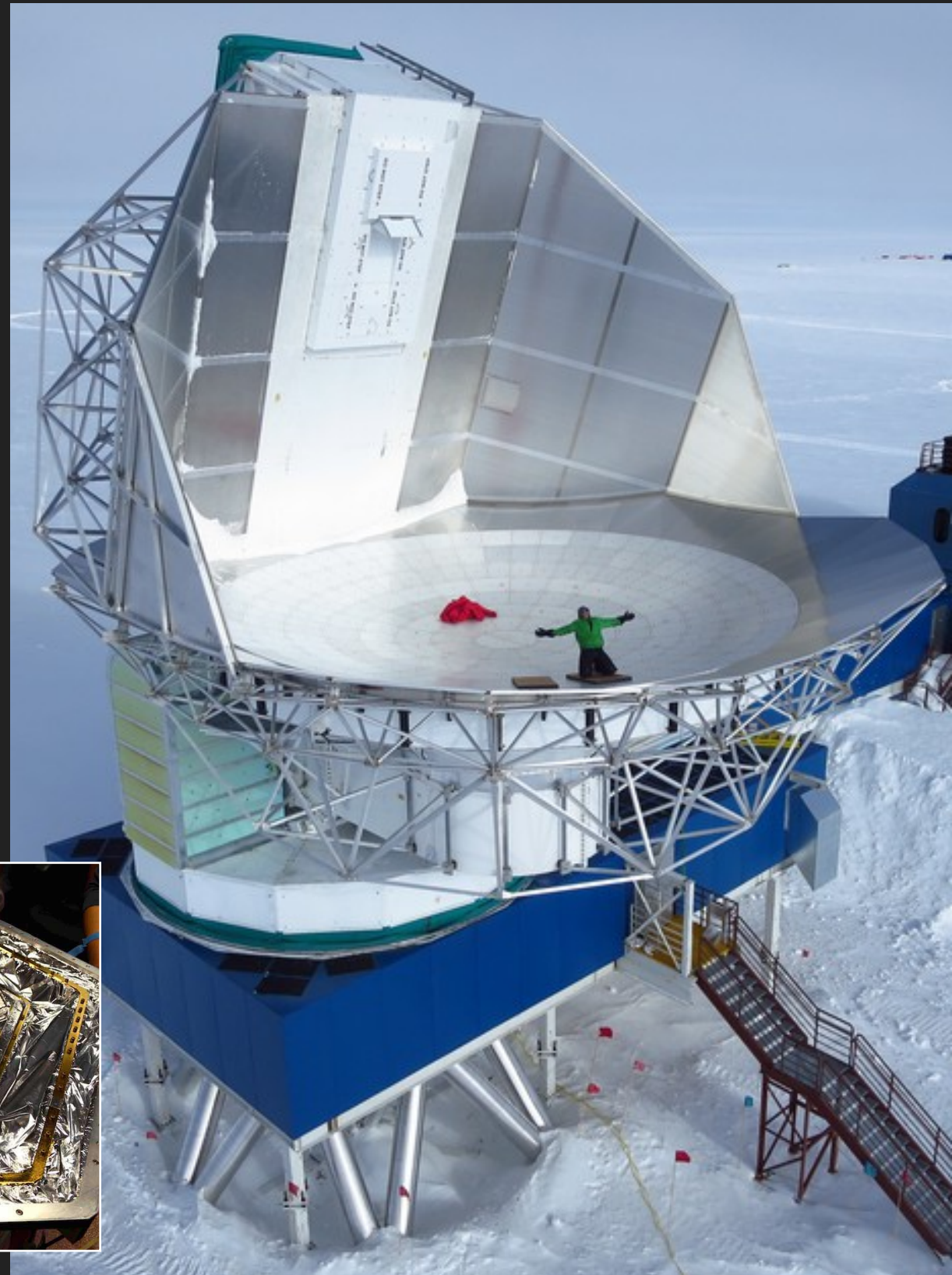
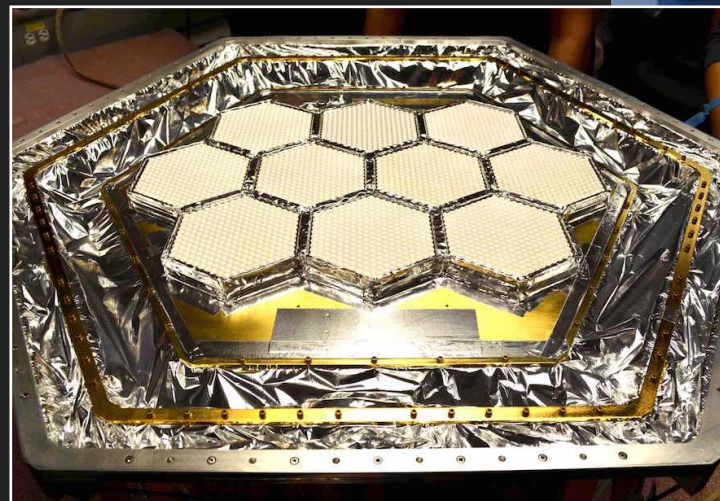
- ▶ **2012: SPTpol**

- ▶ 1600 detectors
- ▶ 90, 150 GHz
- ▶ +polarization



- ▶ **2017: SPT-3G**

- ▶ ~16,200 detectors
- ▶ 90, 150, 220 GHz
- ▶ +polarization

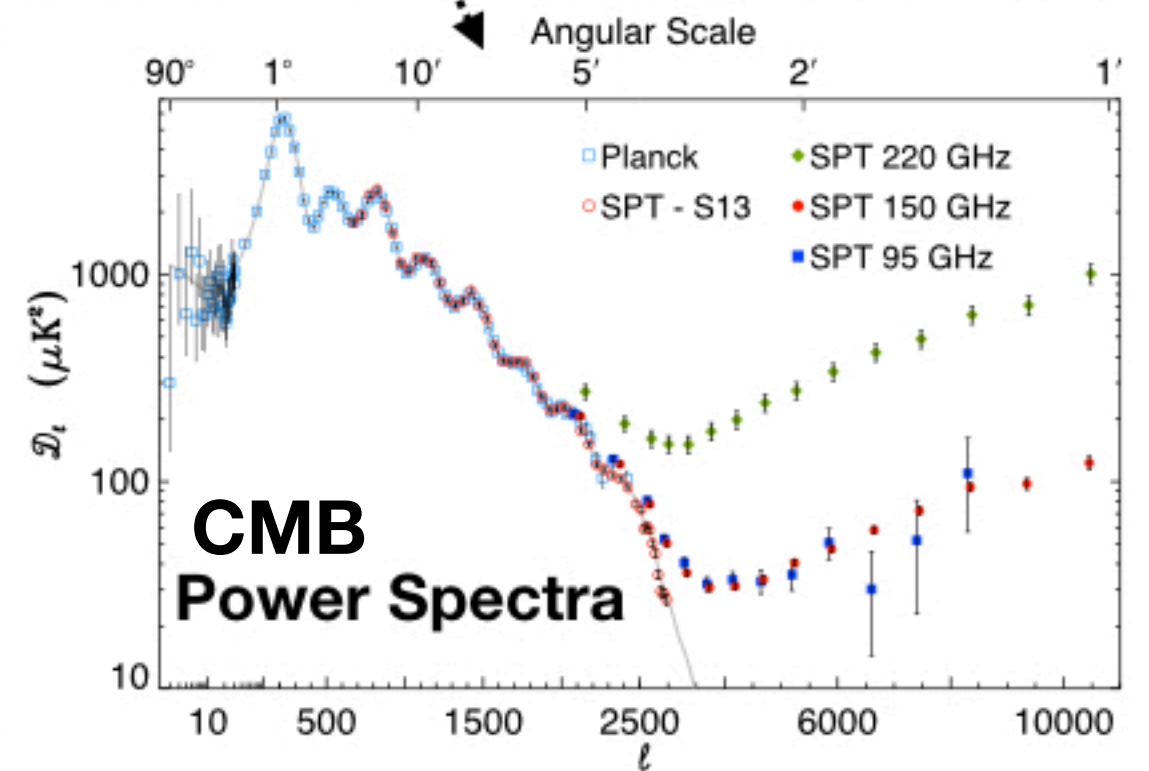
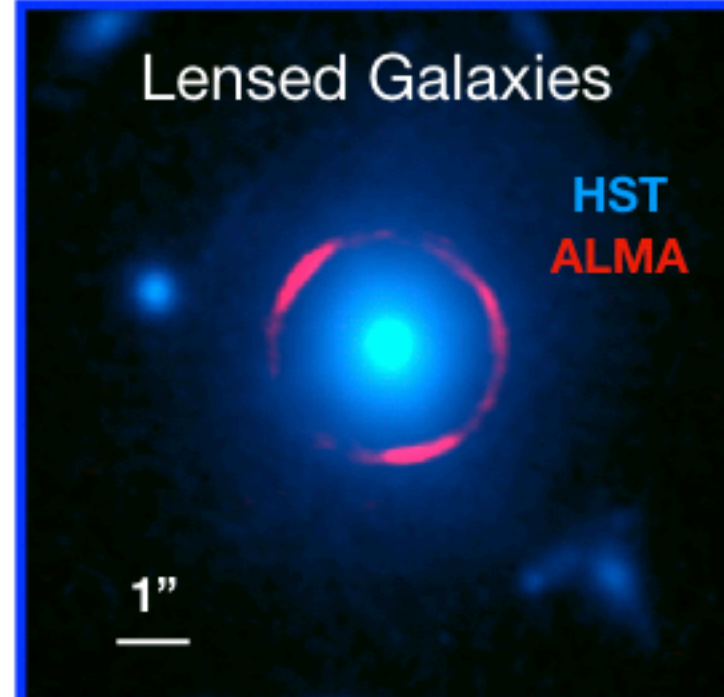
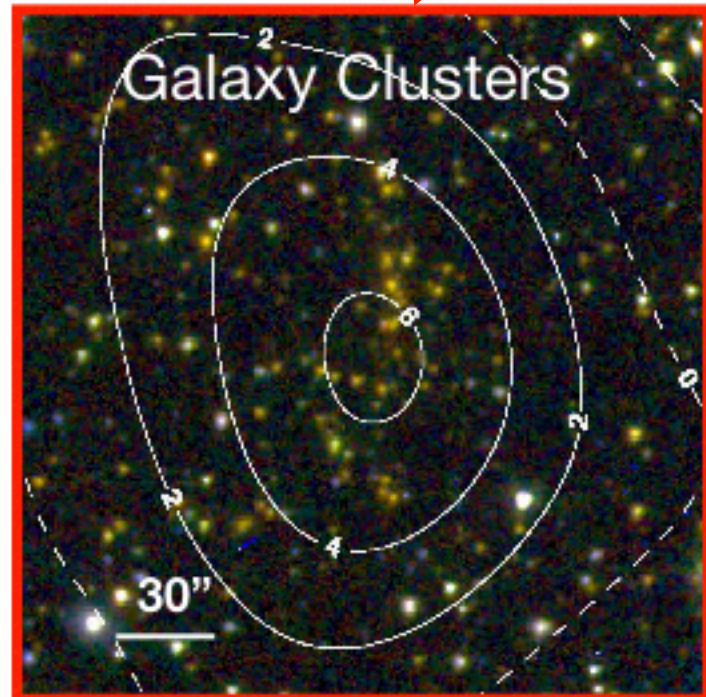


SPTpol

6x deeper
6x finer angular
resolution

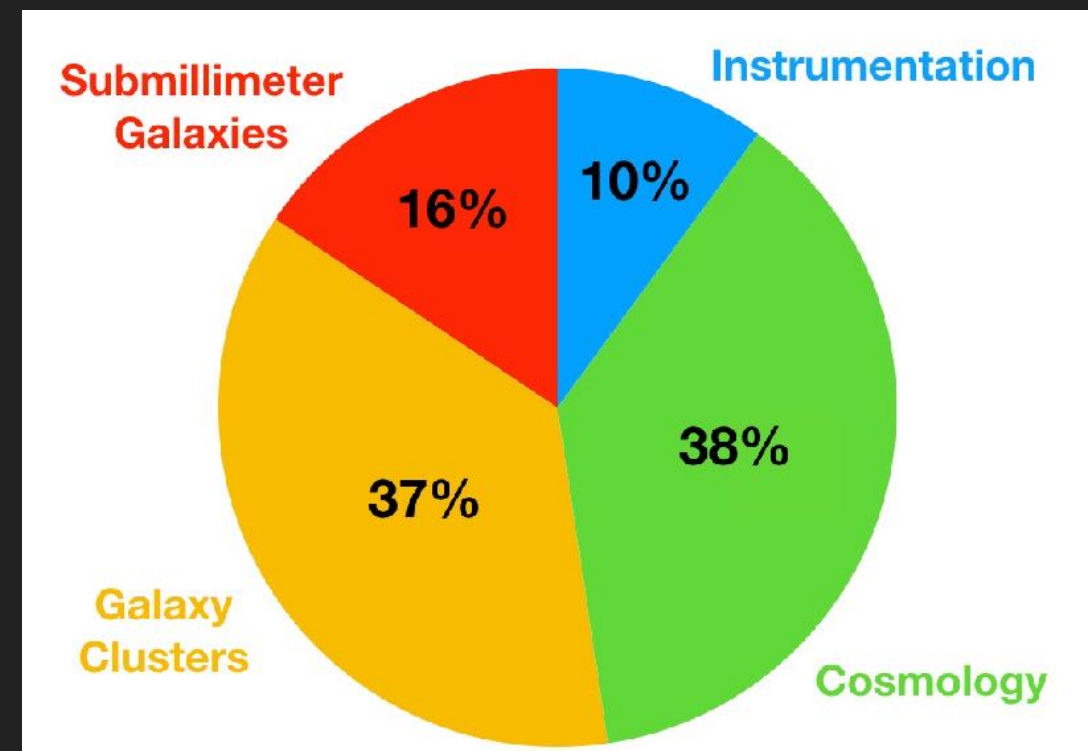
Planck

1°



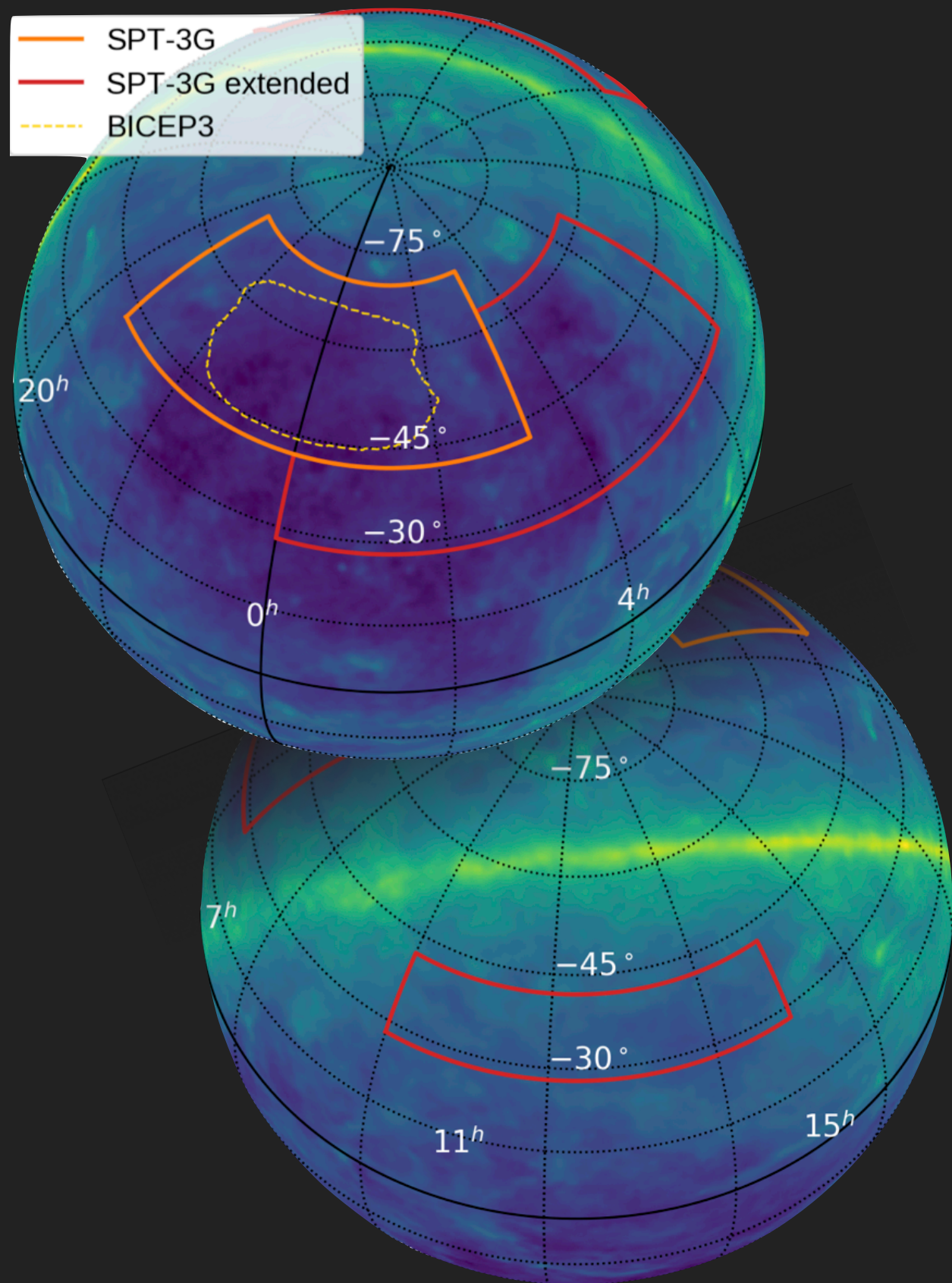
BREADTH OF SPT RESULTS (>130 SCIENCE PUBLICATIONS)

- ▶ **CMB anisotropy:** Power spectra and cosmological parameters
- ▶ **CMB B-Modes:** First detection of lensing B-mode polarization; demonstration of delensing for improved constraints on inflationary tensor-to-scalar ratio
- ▶ **CMB lensing:** power spectra; cross-correlations; cluster-lensing mass calibration
- ▶ **Sunyaev-Zel'dovich (SZ):** Diffuse kinematic and thermal SZ effect constraints: bispectrum, pairwise kSZ, patchy reionization
- ▶ **Galaxy Clusters:** First SZ discovery clusters, cluster catalog and cosmology
- ▶ **High-Redshift Galaxies:** Discovered population of lensed dusty star forming galaxies
- ▶ **Transients:** mm-wave phenomena (GRBs, FRBs), mJy-level monitoring of 1000s of blazars, AGNs
- ▶ Participating in the **Event Horizon Telescope**
- ▶ ...



Publications: pole.uchicago.edu

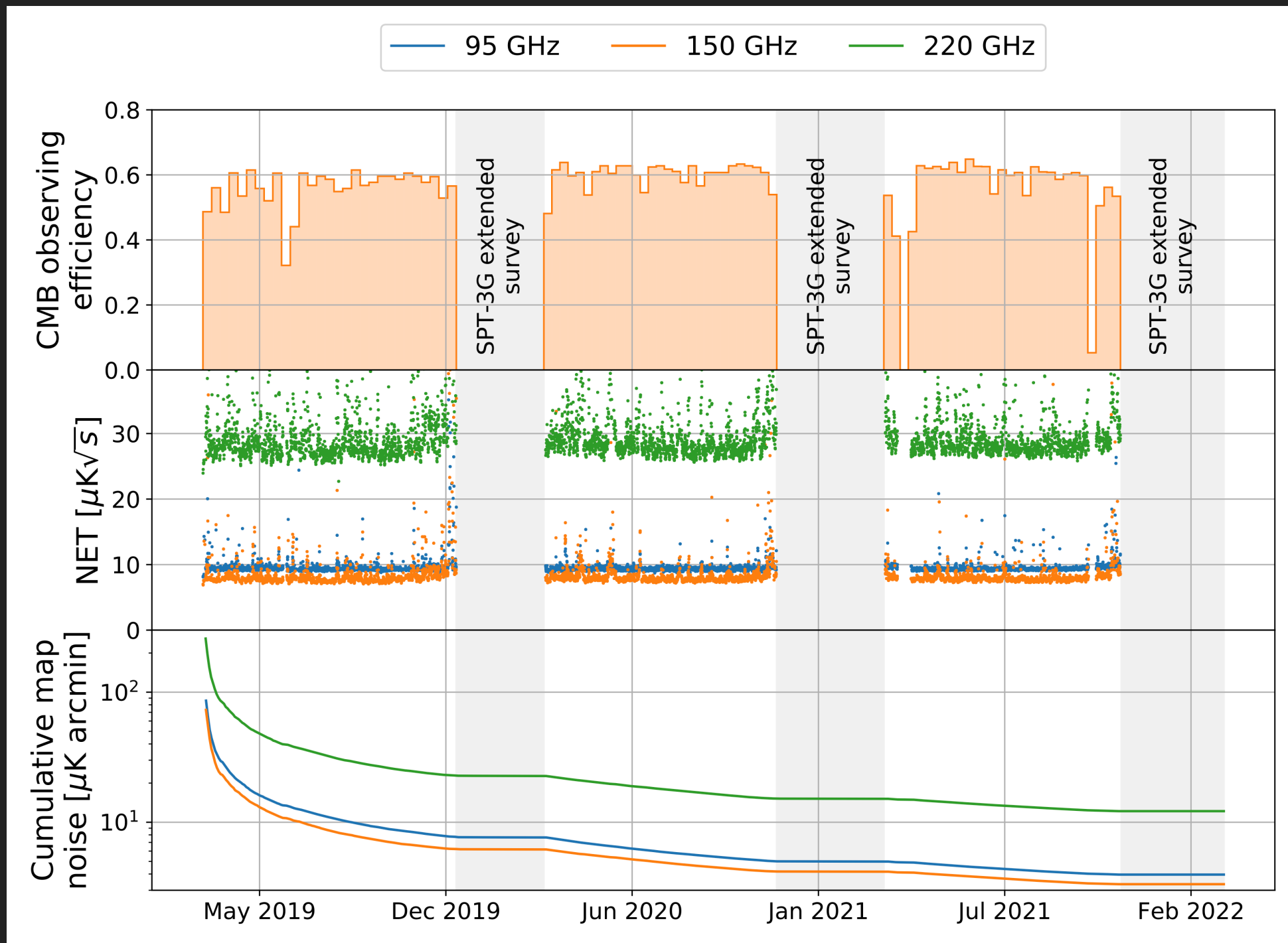
THE SPT-3G 1500 DEG² SURVEY



- ▶ SPT-3G 1500 deg² survey will be ~10x deeper than SPT-SZ
- ▶ Overlaps BICEP Array, to optimize inflationary constraints from CMB delensing

	Obs. Years	Area (deg ²)	95 GHz (uK-arcmin)	150 (uK-arcmin)	220 (uK-arcmin)
SPT-SZ	2007-11	2500	40	17	80
SPTpol-500d	2012-16	500	13	6	-
SPTpol-100d	2012-16	100	10	5	-
SPTpol-2700d	2012-16	2700	47	28	-
SPT-3G (projected)	2018-23	1500	3.0	2.2	8.8

SPT-3G: DATA QUALITY

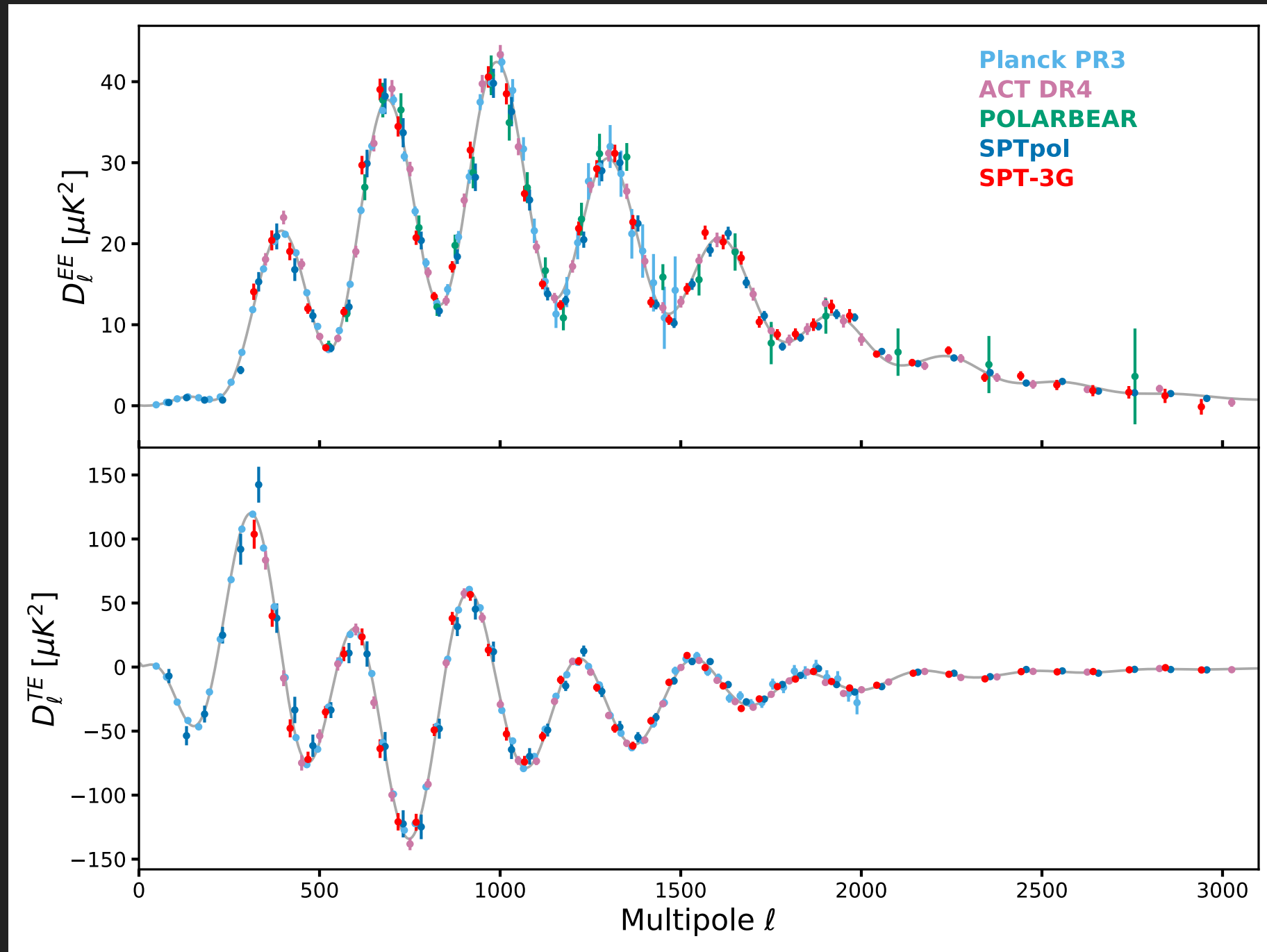


~60% observing efficiency in 9-month observing season

Daily camera sensitivity is stable over season

Expect to reach CMB-S4 wide survey depth by end of 2023

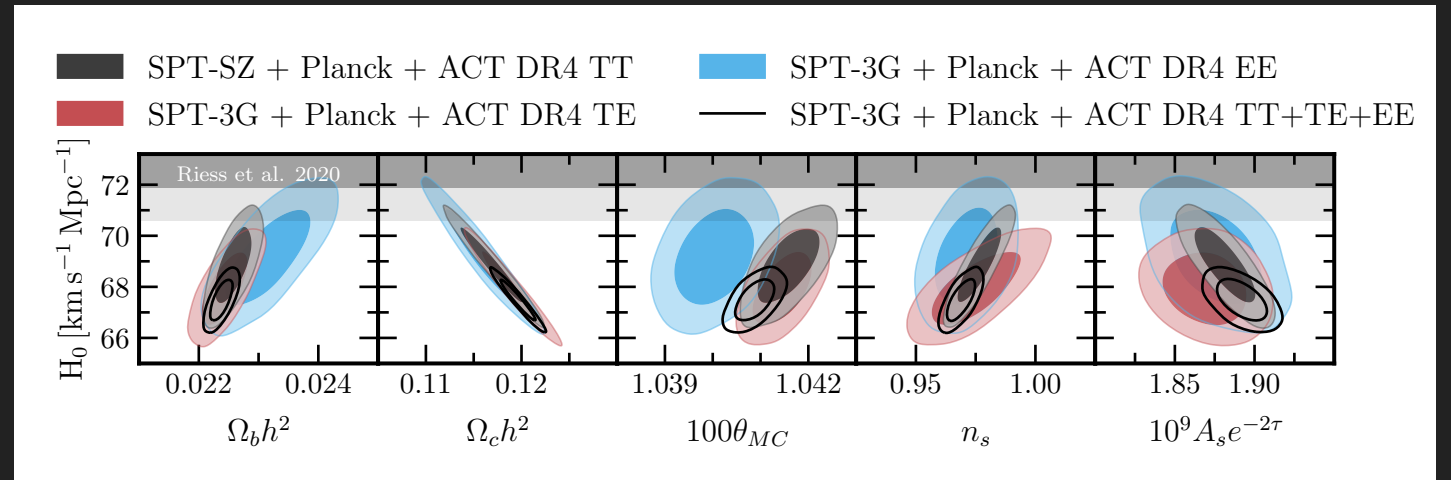
SPT3G: 2018 CMB POWER SPECTRA



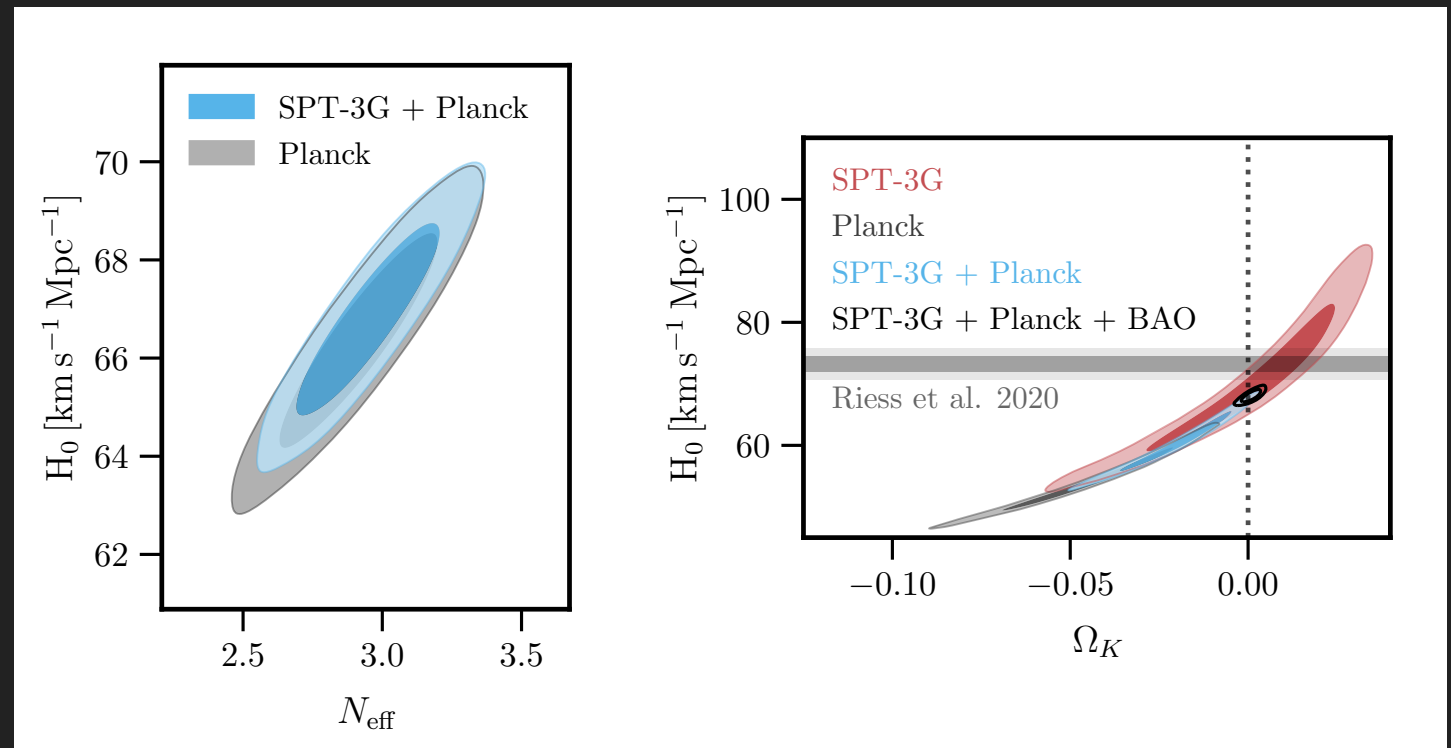
- ▶ 2018: half season with half of full detector count
- ▶ Constraints already comparable to or exceed leading measurements at intermediate scales

SPT3G: 2018 Λ CDM CONSTRAINTS

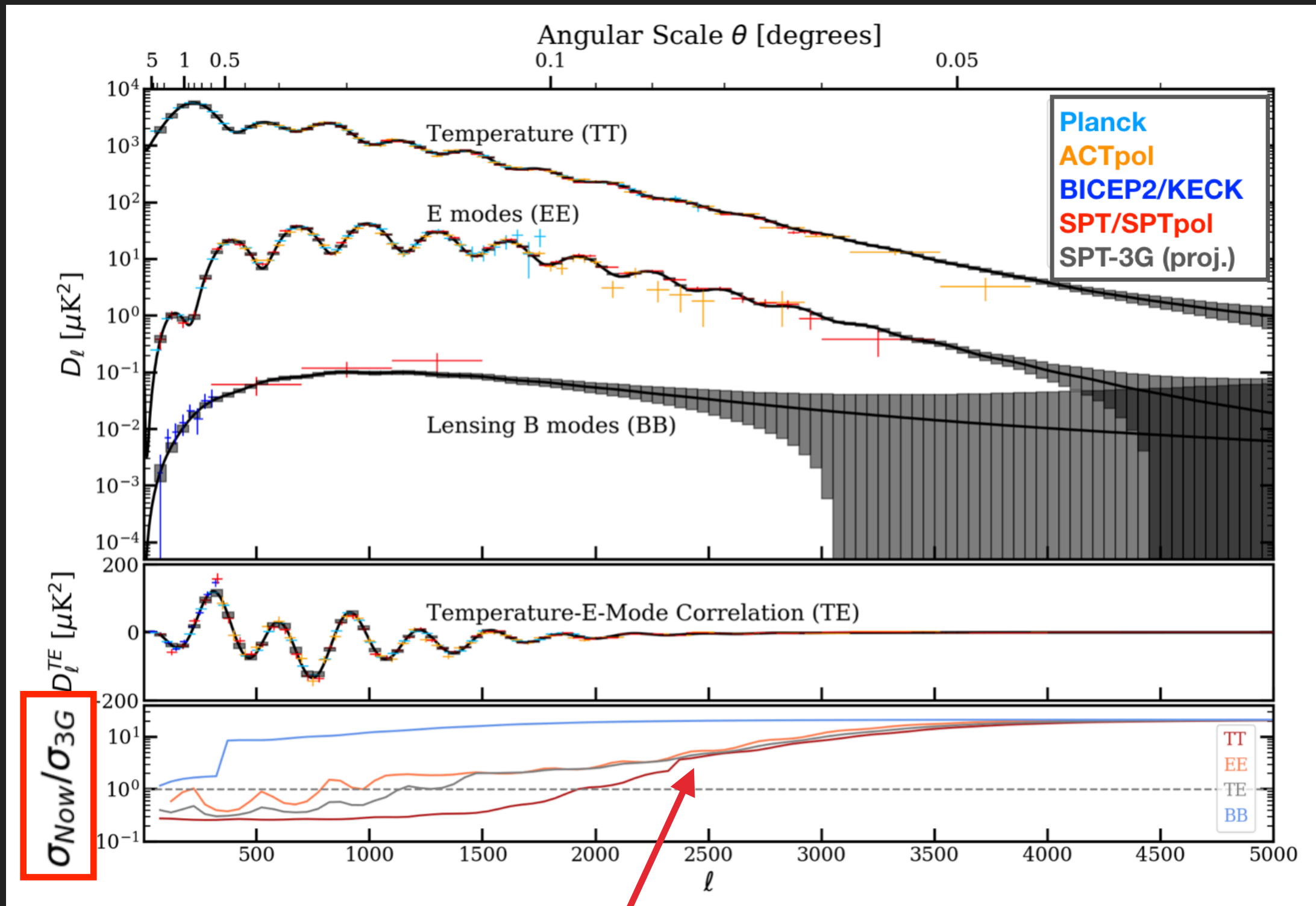
- ▶ Consistent H_0 values between T and P spectra when evaluated across experiments
- ▶ Tightest constraint on H_0 to date
 - ▶ 4.1 σ tension with Riess et al
- ▶ Further model extensions: N_{eff} , Y_p , $\sum m_\nu$, Ω_K
 - ▶ No clear evidence for any extensions
 - ▶ with Planck, reduce volume of parameter space by 1.3-2x



Spectra	Datasets	H_0 [$\text{km s}^{-1} \text{Mpc}^{-1}$]
<i>TT</i>	SPT-SZ + <i>Planck</i> + ACT DR4 ($\ell > 1800$)	68.85 ± 0.97
<i>TE</i>	SPT-3G 2018 + <i>Planck</i> + ACT DR4	67.95 ± 0.94
<i>EE</i>	SPT-3G 2018 + <i>Planck</i> + ACT DR4	69.2 ± 1.2
<i>TT + TE + EE</i>	SPT-3G 2018 + <i>Planck</i> + ACT DR4	67.49 ± 0.53



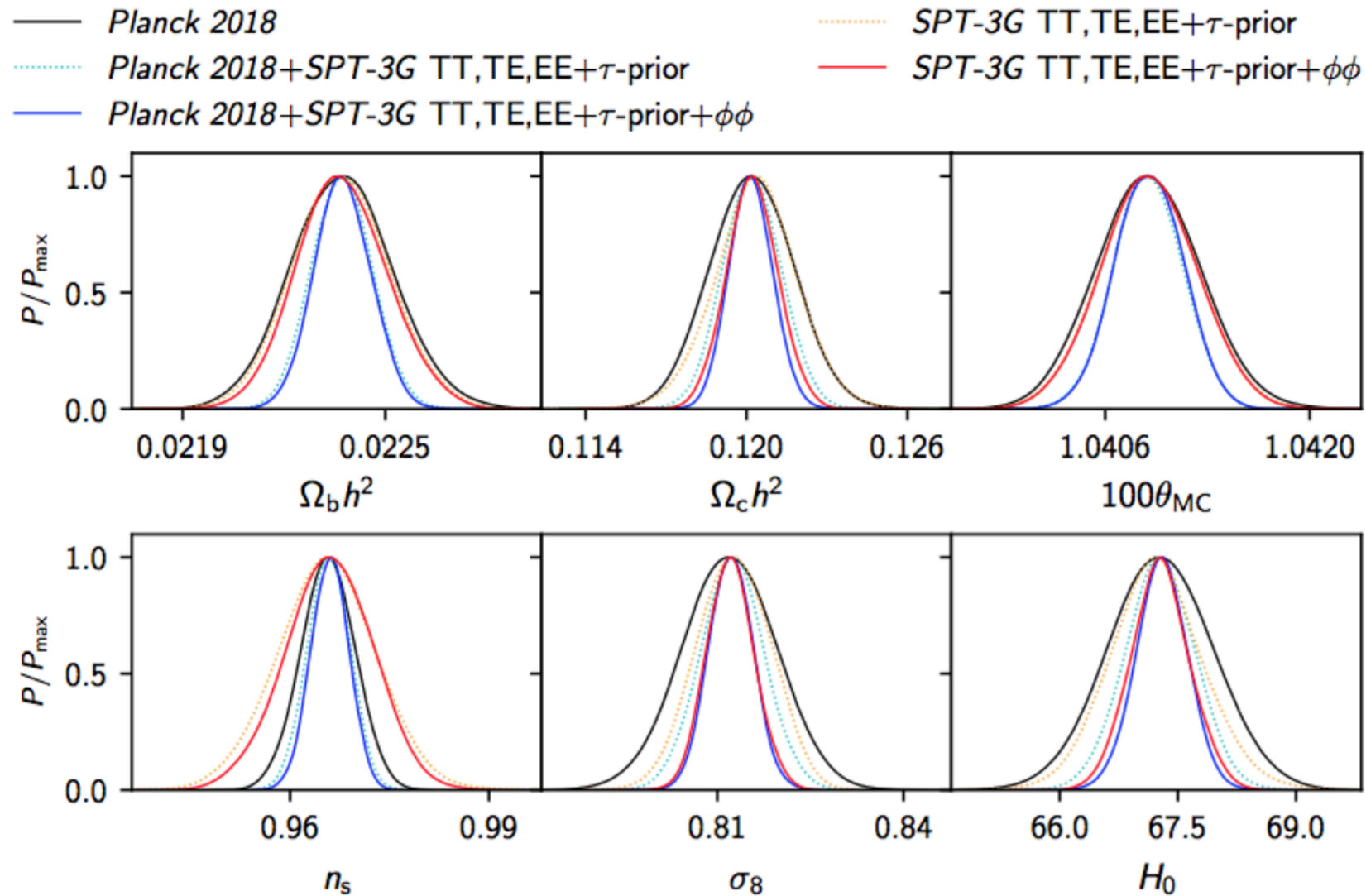
SPT3G FORECAST: CMB POWER SPECTRUM



Improve S/N of CMB power spectra by factors of $> \sim 10$ at $l > 2500$ over current constraints

SPT3G FORECAST: Λ CDM CONSTRAINTS

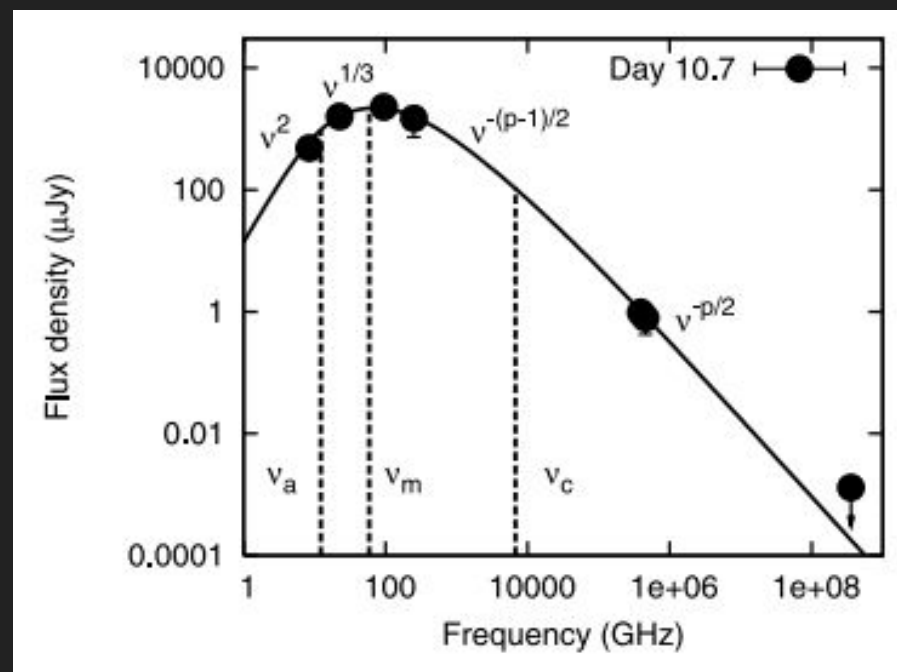
Planck \longrightarrow SPT-3G



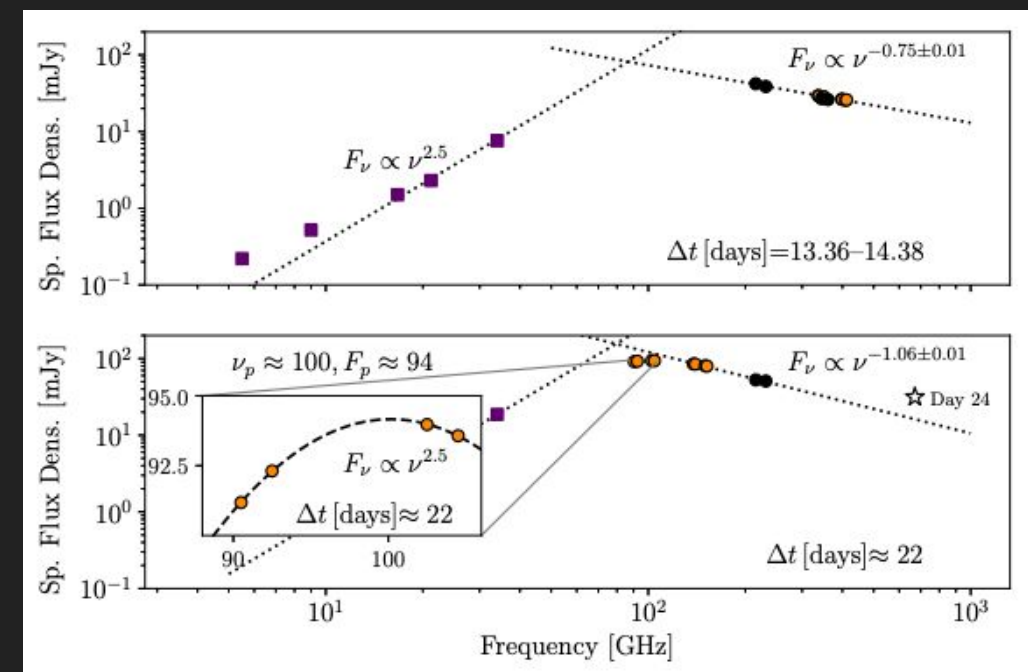
- ▶ SPT-3G alone will do as well as Planck on most parameters (except τ , n_s)
 - ▶ e.g., $\sigma(H_0)=0.6$ km/s/Mpc from SPT-3G lensed TT,TE,EE spectra
- ▶ SPT-3G gives \sim independent cosmological information from high- ℓ CMB polarization spectrum
- ▶ SPT-3G + Planck will improve most parameters $>2x$ over Planck alone

SPT3G: ASTROPHYSICAL TRANSIENTS

- ▶ Exploit CMB observing cadence: repeated daily imaging of large sky area at multiple frequencies
- ▶ Provide useful probe of high-energy astrophysics (AGN, GRB, FRB, stellar flares, ...)
- ▶ No dedicated transient surveys exist between 10GHz and IR frequencies
- ▶ Large discovery potential with online alert system



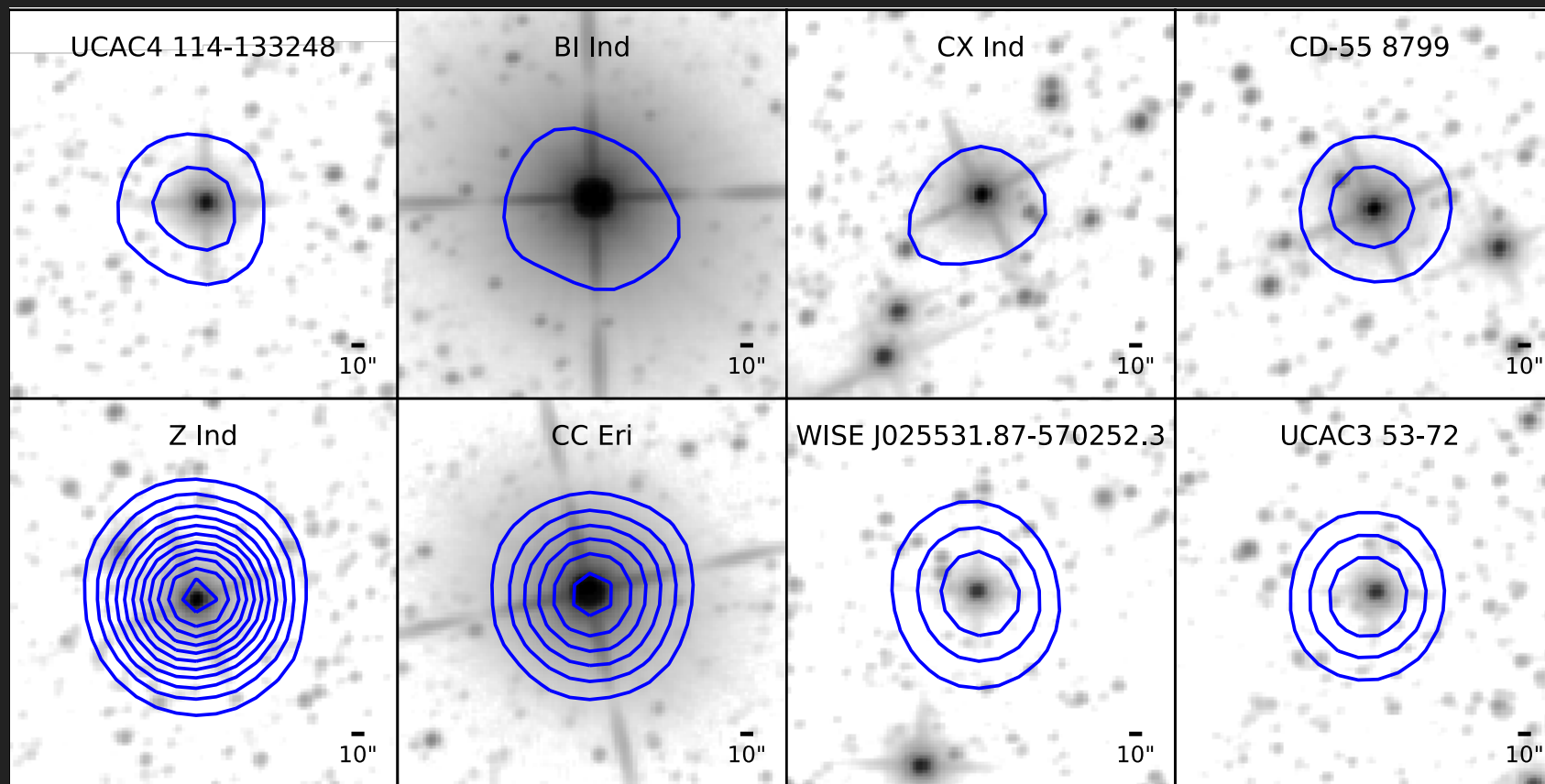
*Spectrum of GRB 070125
(Chandra et al 2008)*



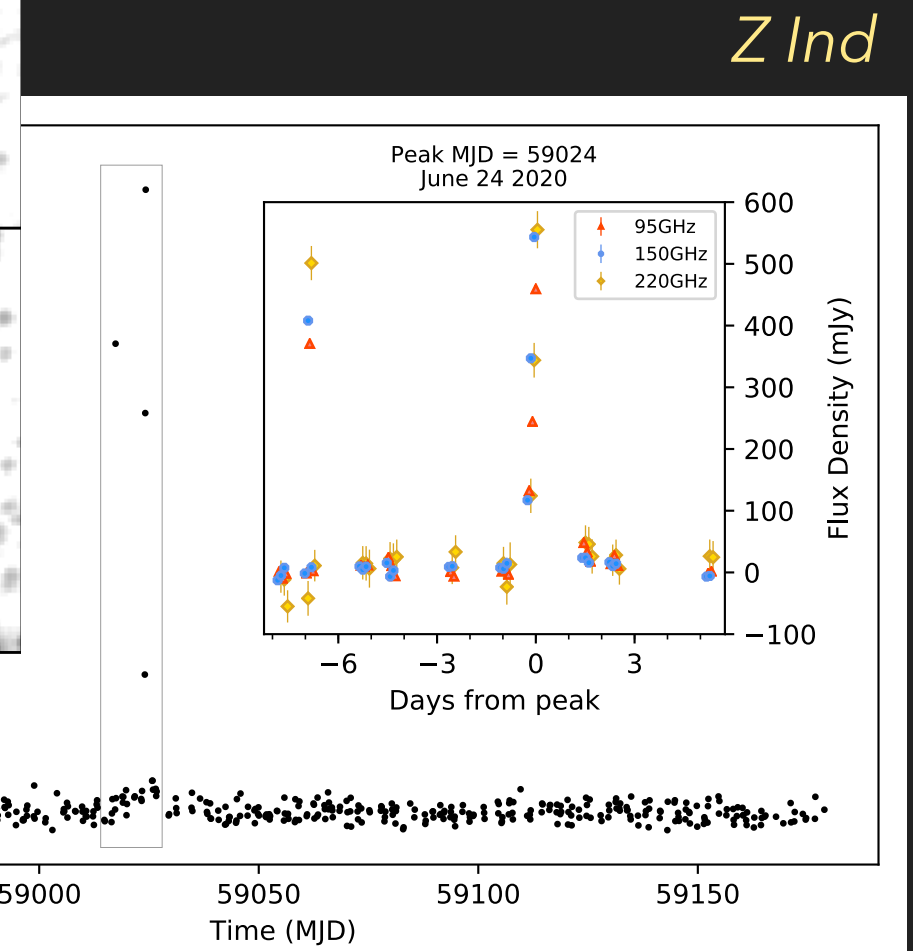
*New type of transient: FBOT
(AT2018cow, Ho et al 2019)*

SPT3G: ASTROPHYSICAL TRANSIENTS

- ▶ First results: 15 transient events in 2019 dataset
- ▶ Most are stellar flares (likely magnetic reconnection events?)
 - ▶ up to 2 Jy in brightness, flares as short as 20 min, some flare more than once

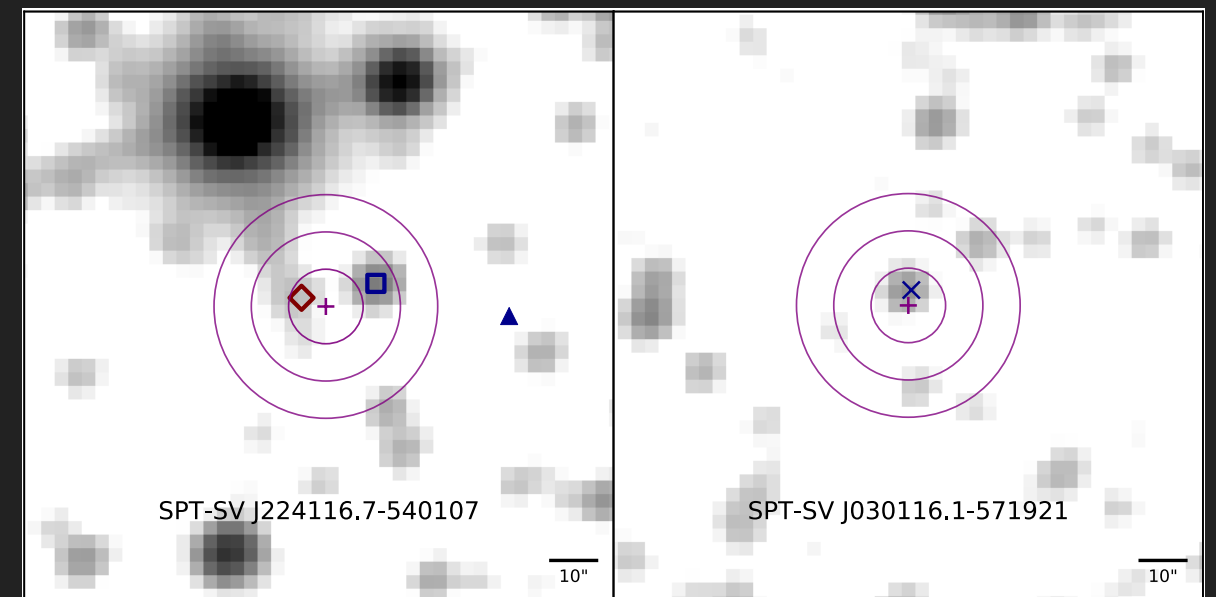
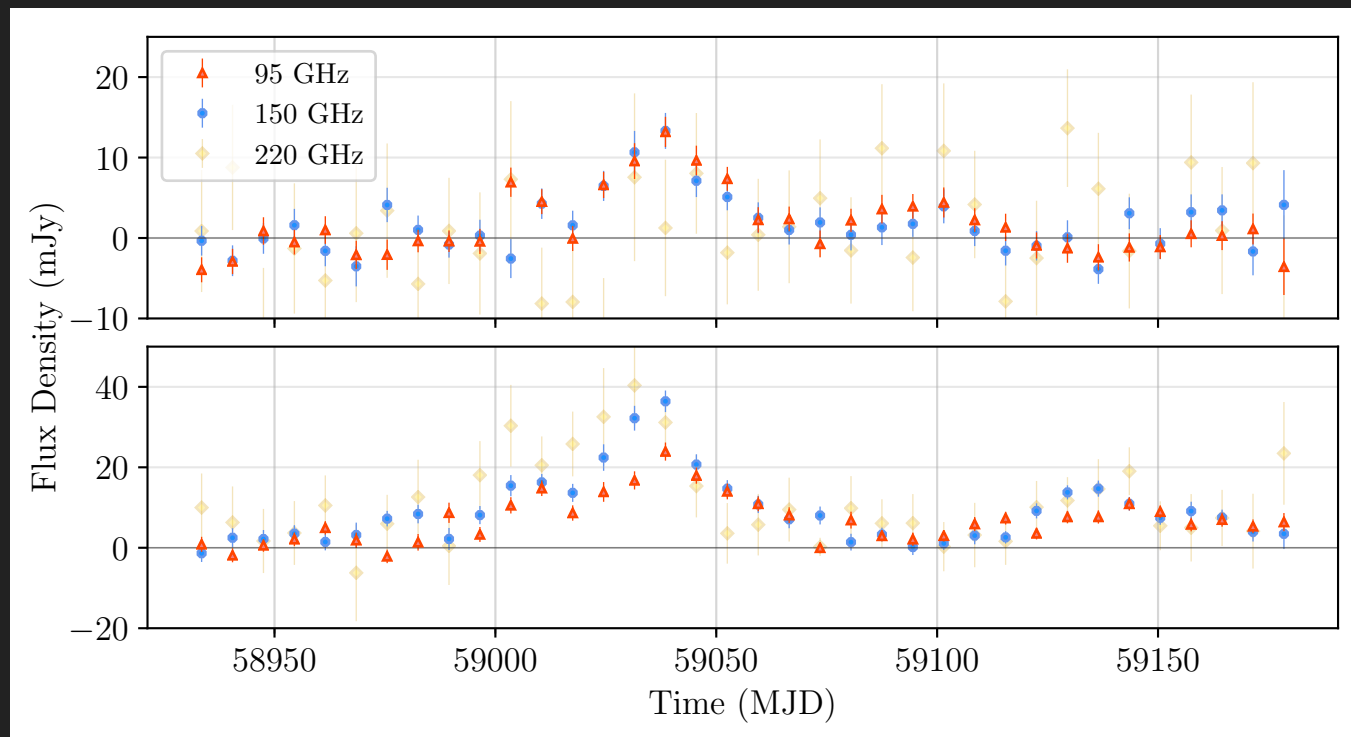


unWISE 3.4um W1



SPT3G: ASTROPHYSICAL TRANSIENTS

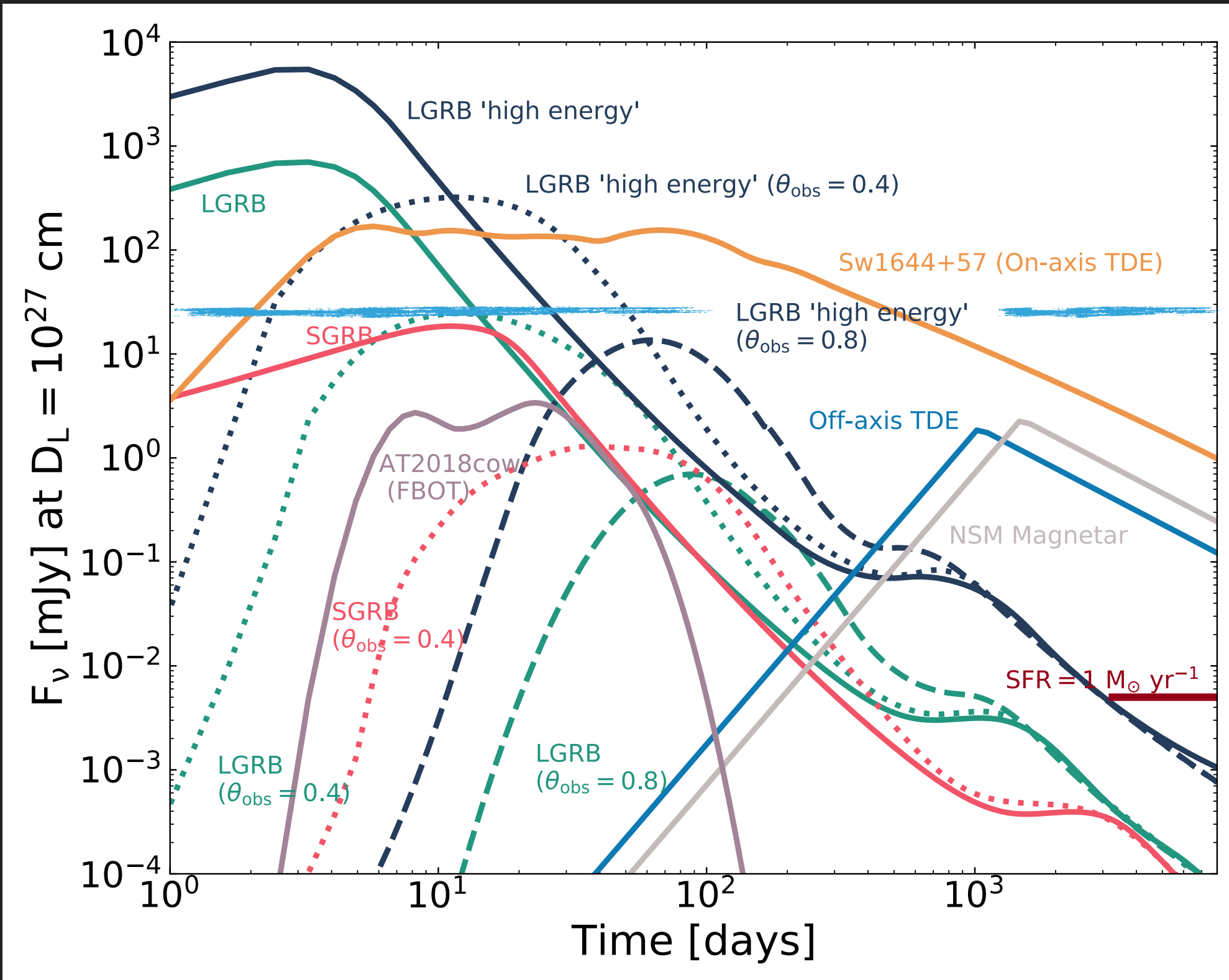
- ▶ First results: 15 transient events in 2019 dataset
- ▶ Two extragalactic long-duration flares
 - ▶ Super variable AGN? Something else? Follow-up in progress



unWISE 3.4um W1

4x / 15x increased flux relative to 2019 average

SPT3G: ASTROPHYSICAL TRANSIENTS



CMB-S4 Deep / SPT-3G
10 σ daily limit

▶ Lots of
discovery
potential!

SPT3G: SEARCH FOR ULTRA-LIGHT AXION-LIKE PARTICLES

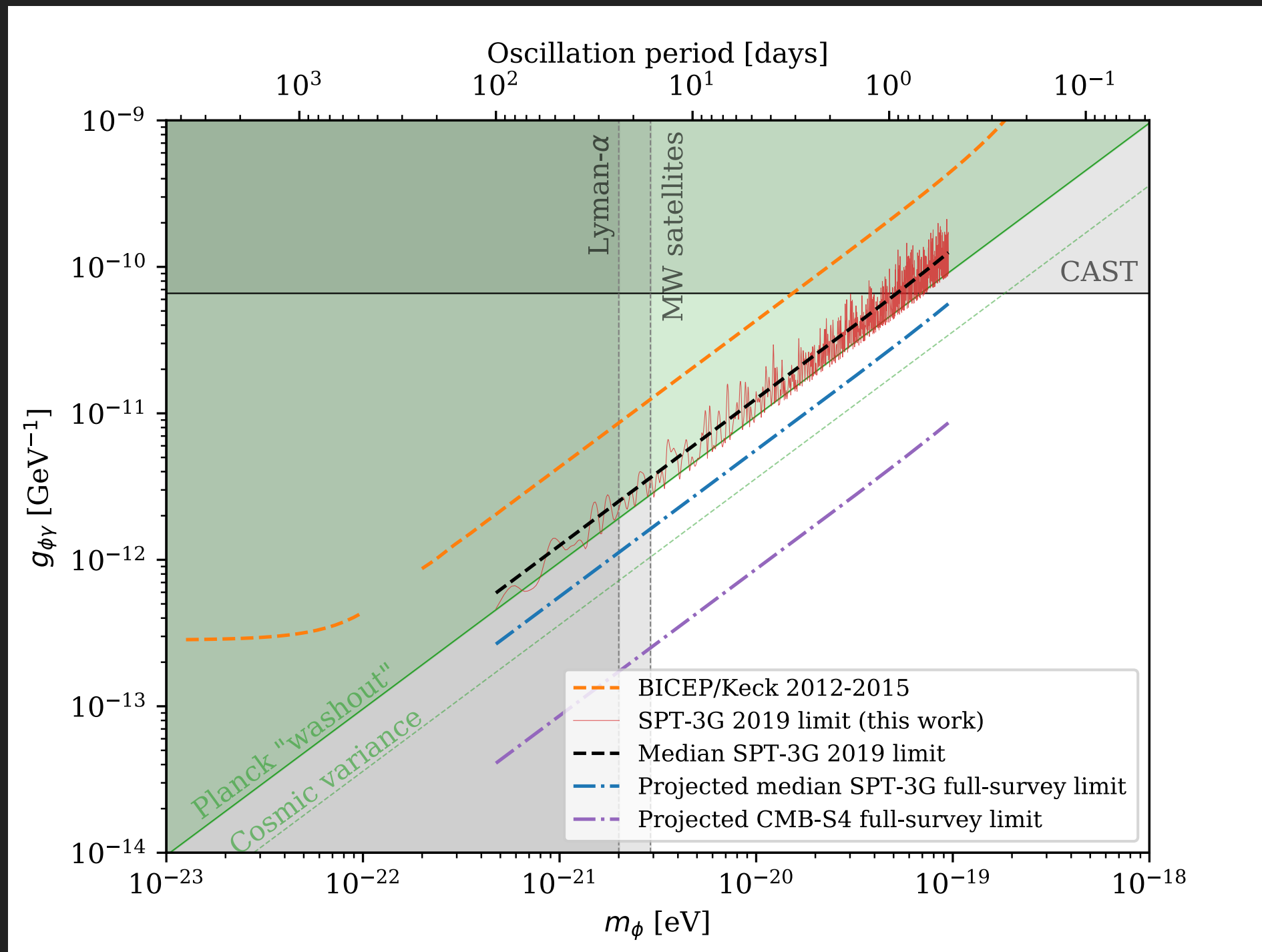
- ▶ Exploit axion-photon coupling to search for evidence of axion-like dark matter candidates
- ▶ Oscillation of axion field results in rotation of linear polarization of photons along line of sight

$$\begin{aligned} Q(t) &= \epsilon(Q_0 - \rho(t)U_0) \\ U(t) &= \epsilon(U_0 + \rho(t)Q_0) \end{aligned}$$

$$\rho(t) = g_{\phi\gamma}\phi_0 \cos(m_\phi t + \alpha)$$

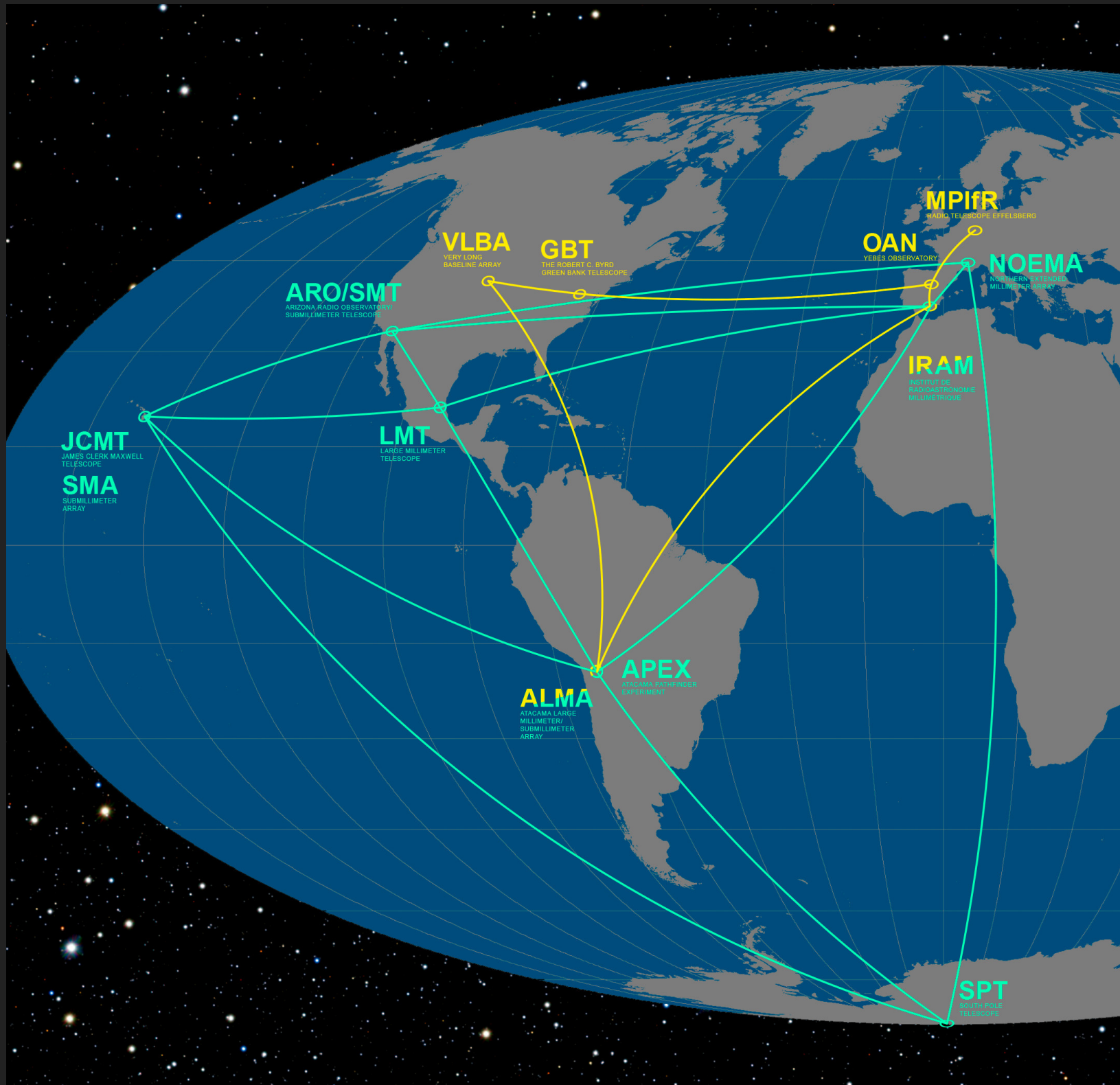
- ▶ Axion signatures in CMB polarization:
 - ▶ **Polarization washout:** average axion field oscillations to reduce polarization intensity of CMB photons -- expected to be small
 - ▶ **AC birefringence:** Local axion field oscillations create time-dependent polarization rotation in CMB photons
 - ▶ SPT3G observing cadence probes time scales from hours to days!

SPT3G: SEARCH FOR ULTRA-LIGHT AXION-LIKE PARTICLES



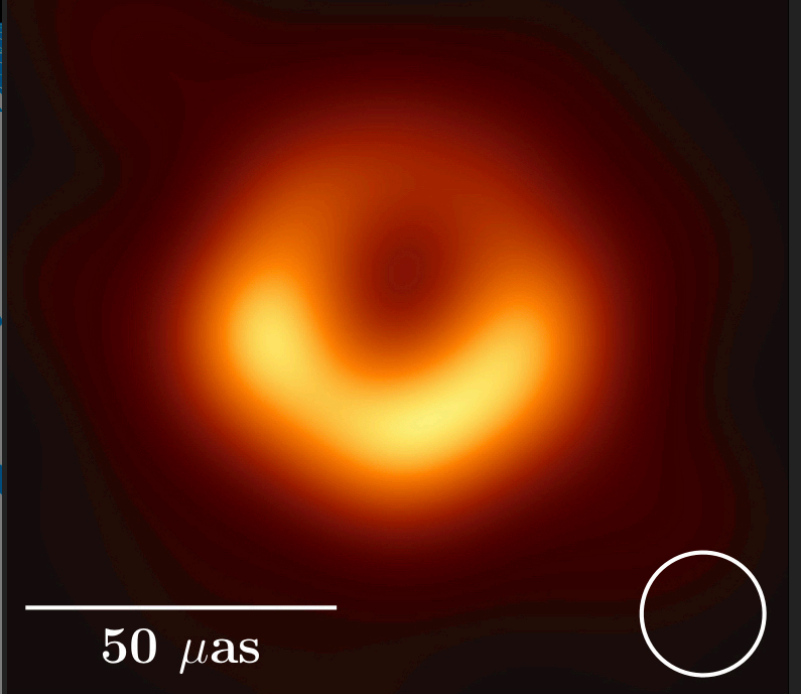
- ▶ $g_{\phi\gamma} < 1.18 \times 10^{-12} \text{ GeV}^{-1} \times (m_{\phi} / 10^{-21} \text{ eV})$ [95% CL] -- 3.8x improved limit

EVENT HORIZON TELESCOPE



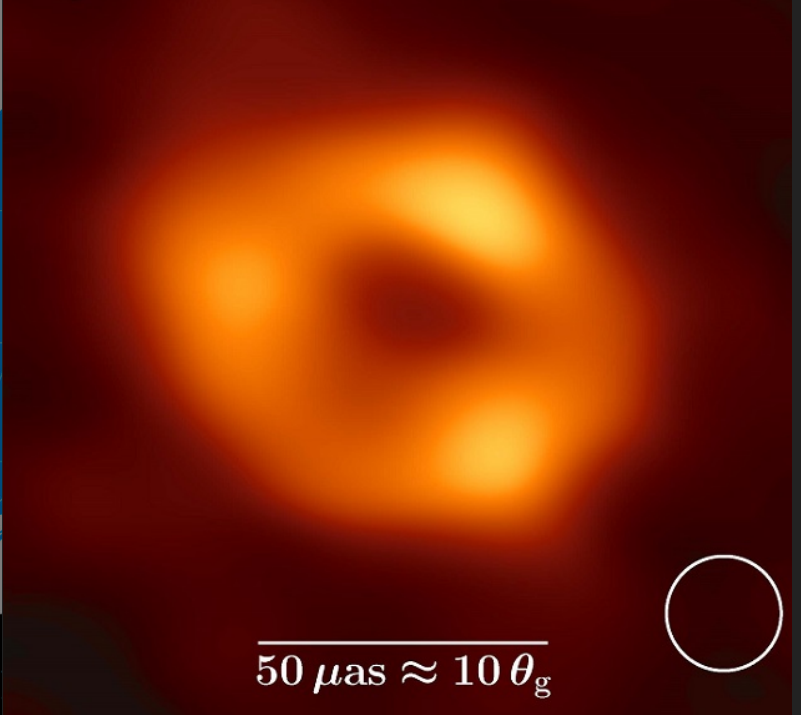
M87*

April 11, 2017

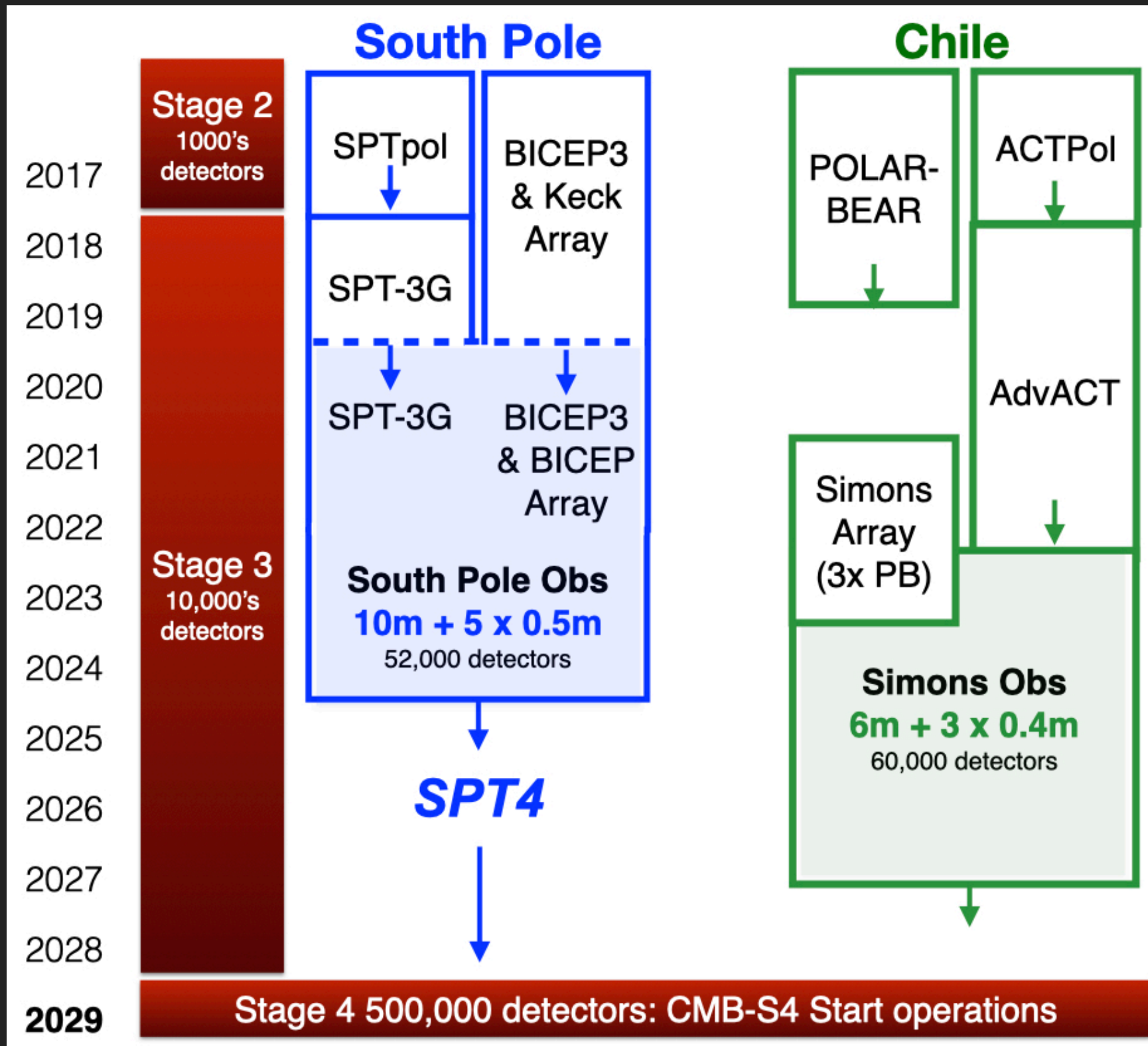


Sgr A*

April 7, 2017



FUTURE DIRECTIONS



- ▶ 5-year gap between end of SPT3G and start of CMB-S4
- ▶ SPT4 proposed to utilize the SPT submm-quality telescope during the gap

SPT4 SCIENCE



▶ Recombination

- ▶ First detection of CMB Rayleigh Scattering, new probe of cosmic expansion history, and cosmology. (Dibert et al [2205.04494], Zhu et al [2205.04496])

▶ Reionization

- ▶ Constrain duration and redshift of reionization via kSZ

▶ Growth of galaxies and clusters

- ▶ Detect growth of massive galaxies and clusters from $1 < z < 9$

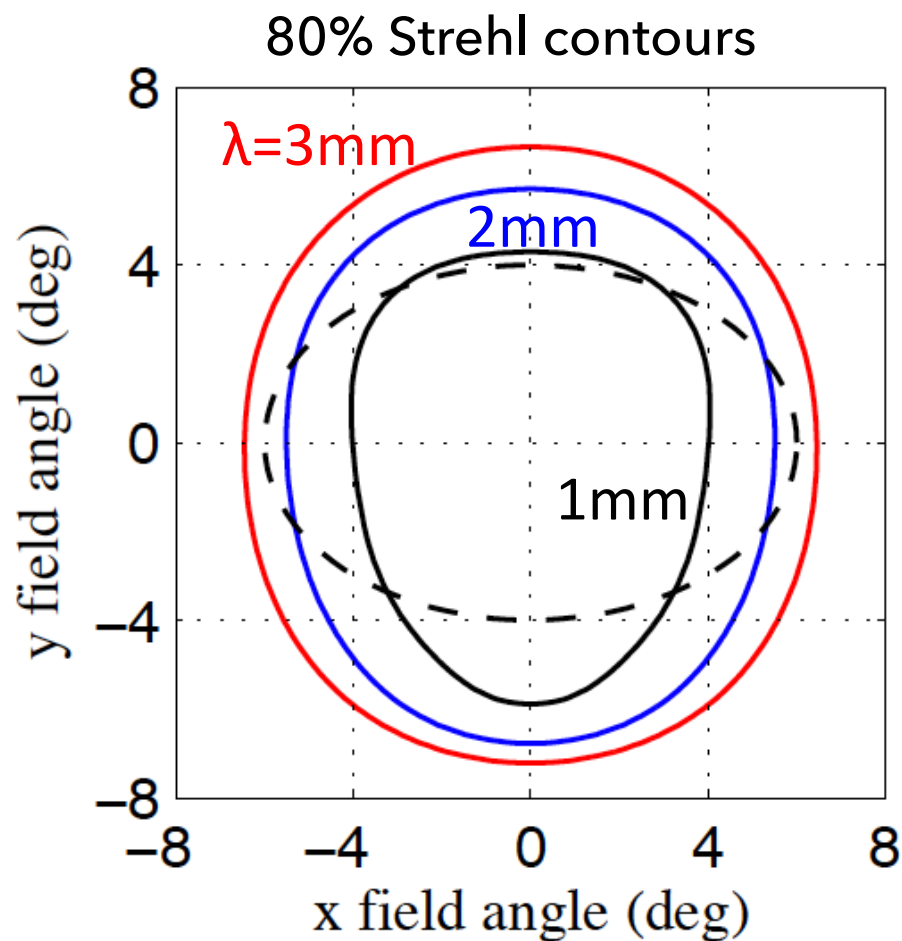
▶ Dust and star formation in the galaxy

SUMMARY

- ▶ SPT-3G survey is ongoing
 - ▶ First results from 2018 season published, with impressive CMB sensitivity and performance at large scales
 - ▶ SPT-3G science publications from 2019-2020 seasons coming soon
 - ▶ Rich astrophysical transient program
- ▶ SPT-3G science forecasts through 2023 season
 - ▶ Λ CDM constraints as good as Planck on most cosmological parameters
 - ▶ With Planck, factor of $\sim 2x$ improved constraints on N_{eff} and neutrino mass
 - ▶ With BICEP Array, factor of $\sim 10x$ improvement on current BK15 tensor-to-scalar ratio constraint
- ▶ Future plans for CMB science at the South Pole
 - ▶ SPT4 to enable first detection of CMB Rayleigh Scattering, and to constrain reionization via the kSZ effect
 - ▶ CMB-S4 coming online at the end of the decade

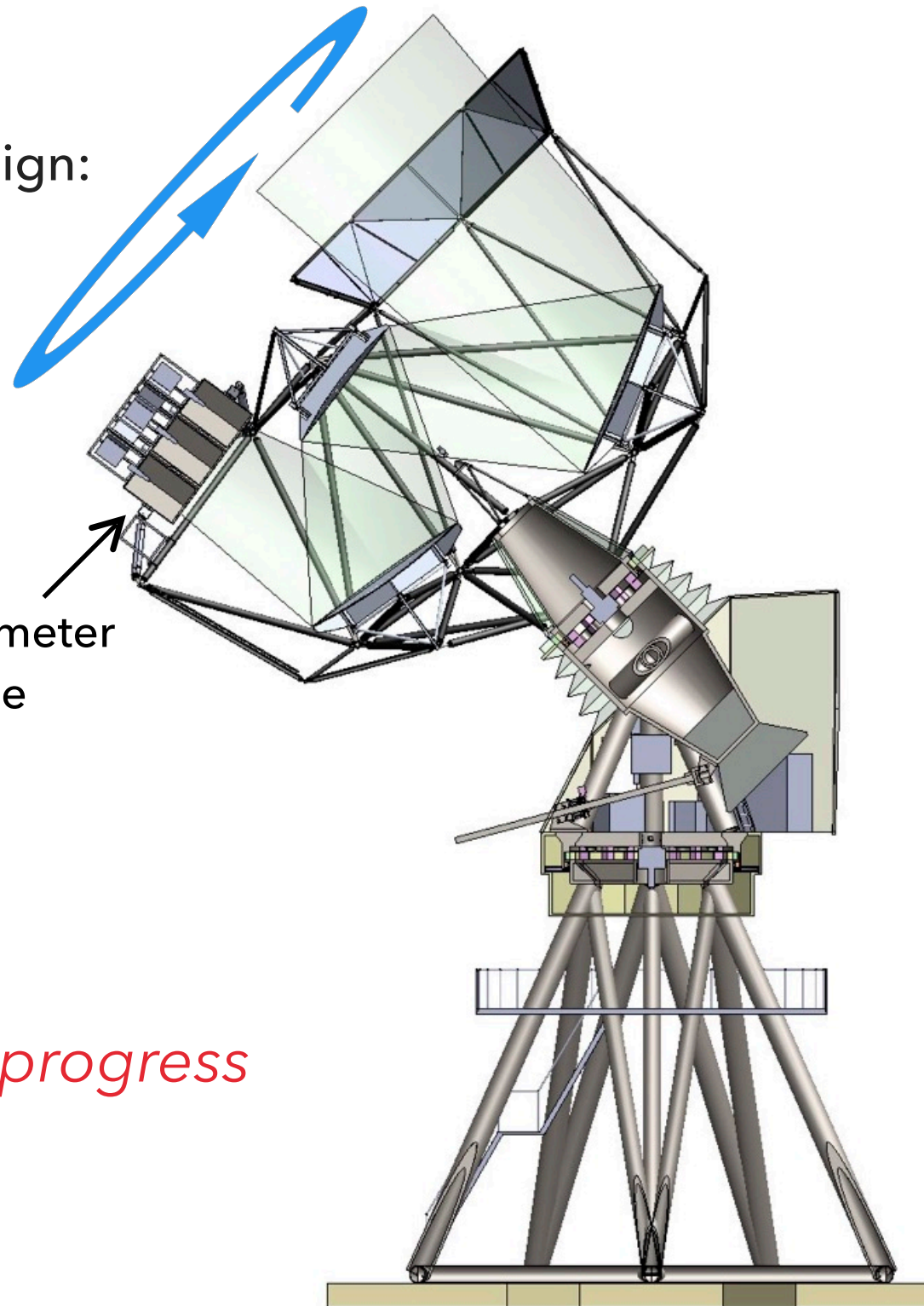
SP-TMA: SOUTH POLE THREE MIRROR ANASTIGMAT

- ▶ Degree B-modes and arc minute resolution with extremely high throughput.
- ▶ 5-meter Three Mirror Anastigmat (TMA) telescope design:
 - ▶ 75 deg² field of view
 - ▶ 424k/136k/63k Fλ pixels at λ=1/2/3mm
 - ▶ Monolithic mirrors (low scattering)
 - ▶ Boresight rotation for polarization systematics



3.5 m diameter focal plane

Primary mirror prototyping in progress



Padin, Applied Optics, 57, 9, 2314 2018

CMBS4 FORECASTS

